ENGINEERING DESIGN FOR THE PBFA-II PULSE FORMING SECTION*

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Abstract

This paper presents an overview of the conceptual and detailed mechanical design of the PBFA-II Pulse Forming Section. The design goals were configuration specification, modularity for ease of installation and maintenance, durability and low cost. The design process began by determining the basic configuration. As was true throughout the design, access for ease of maintenance was a major driving factor. Initial assembly requirements dictated a design of separate, modular units for the intermediate store, line one, and line two/three. Integration with the laser system used to trigger the main gas switch put location, stability and adjustment requirements on both the intermediate store and line one. Cost forced the hardware to be fabricated of aluminum. Design for ease of fabrication further held these costs down. Survival in the water shock environment was addressed through specific design and weld techniques. Critical surfaces on all components had to be capable of carrying the high voltages and currents of the machine. The design was developed through prototype testing in the one module machine, Demon.

Introduction

PBFA-II is a 100 terawatt driver for inertial confinement fusion research. Design started on the machine in early 1981 with the initial shot date set for January, 1986. The machine is divided into three main sections characterized by the electrical insulating material used; the oil section, the water section and the vacuum section. The oil section contains 36 Marx generators with a relatively long output pulse (1 microsecond). The water section, the subject of this paper, contains 36 pulse forming lines (PFLs) which compress the pulse in time to 50 nanoseconds wide. The PFLs consist of an intermediate storage capacitor, pulse forming lines one, two and three, and a coax to parallel flat plate transition section as shown in Fig. 1. A 4 joule KrF laser, located in the basement below the machine, triggers the SF6 insulated gas switch in each PFL, providing the required machine simultaneity. The vacuum section contains the plasma opening switches which compress the pulse to 20 ns wide raising the power to greater than 100 TW and the ion diode.

Conceptual Design

PBFA-II, like PBFA-I, is circular with 36 identical accelerators arranged like spokes in a wheel, aimed at the center. The conceptual design of the pulse forming section was driven by the design of the vacuum insulator stack. The insulator stack is a right circular cylinder 3.4 meters in diameter. Eight individual modules make up the stack. The assembled stack height is 4.6 meters. Each PFL feeds two adjacent modules of the insulator stack. Each insulator module is fed at nine locations around its periphery. The PFL's are at four different levels in the tank with centerlines 1, 1.7, 3, and 3.8 meters off the tank floor.

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Two configurations for the oil/water barrier and PFL structure were considered. The first was known as the 1-2-3-4 design, the second the over and under design. (See Fig. 2) The over and under design was eventually chosen because the laser could conveniently be brought straight up out of the basement and the PFL support structure appeared simpler.

Intermediate Store

The intermediate storage capacitor is a cylindrical capacitor with an inner cylinder diameter of 0.86 meters and an outer cylinder diameter of 1.5 meters. The length of the intermediate store is 1.9 meters. The intermediate store is electrically charged by the Marx generator to a voltage of approximately 5.2 MV in 850 nanoseconds. The laser triggered gas switch is mounted to the front of the inner cylinder. Triggering the gas switch discharges the intermediate store and charges line 1.

Mechanically the intermediate store had very stringent tolerances placed on its fabrication. Both inner and outer cylinders were required to be cylindrical within 1.5 mm in order to maintain the uniform electrical field in the gap between inner and outer. The fabricator accomplished this using rolled and welded 0.19 inch (4.8mm) thick 6061-T6 aluminum without machining the cylinders, an impressive achievement. Both inner and outer had to provide for movement of the tank wall and the 1.5 meter diameter polyurethane oil/water barrier during fluid fill and drain. This movement was estimated at 9.5 mm. Accomodation for this movement was provided on the outer cylinder by separating the outer cylinder from the field shaper which bolts to the tank wall. The outer cylinder mounts directly to the floor of the water tank. A commercially available finger contact strip riveted to the field shaper provides sliding electrical contact with the outer cylinder. The inner cylinder has a sliding end plate which attaches to the gas switch. A simple polyethylene slider guides the motion and the same type contact strip is used to make electrical contact.

Line one

Pulse forming line one is a cylindrical transmission line attached to the output end of the laser triggered gas switch. Line one charges to a voltage of 4.6 MV in approximately 130 ns. Self-breaking water switches mounted on the output end of line one transfer the energy to line 2.

Structurally, line one supports the gas switch, the gas switch end of the intermediate store, and the laser canister. Main support rings are located adjacent to the gas switch. The inner support ring is positioned and supported from the outer support ring by six polycarbonate support rods. The laser canister, which contains the final laser turning mirror and the focusing lens, bolts to the inner support ring. The 180 kg gas switch is cantilevered off the laser canister. The moment generated by the gas switch is transmitted through a lever arm and another polycarbonate support rod to an outer support rib which runs between the outer support ring and the prepulse shield one.

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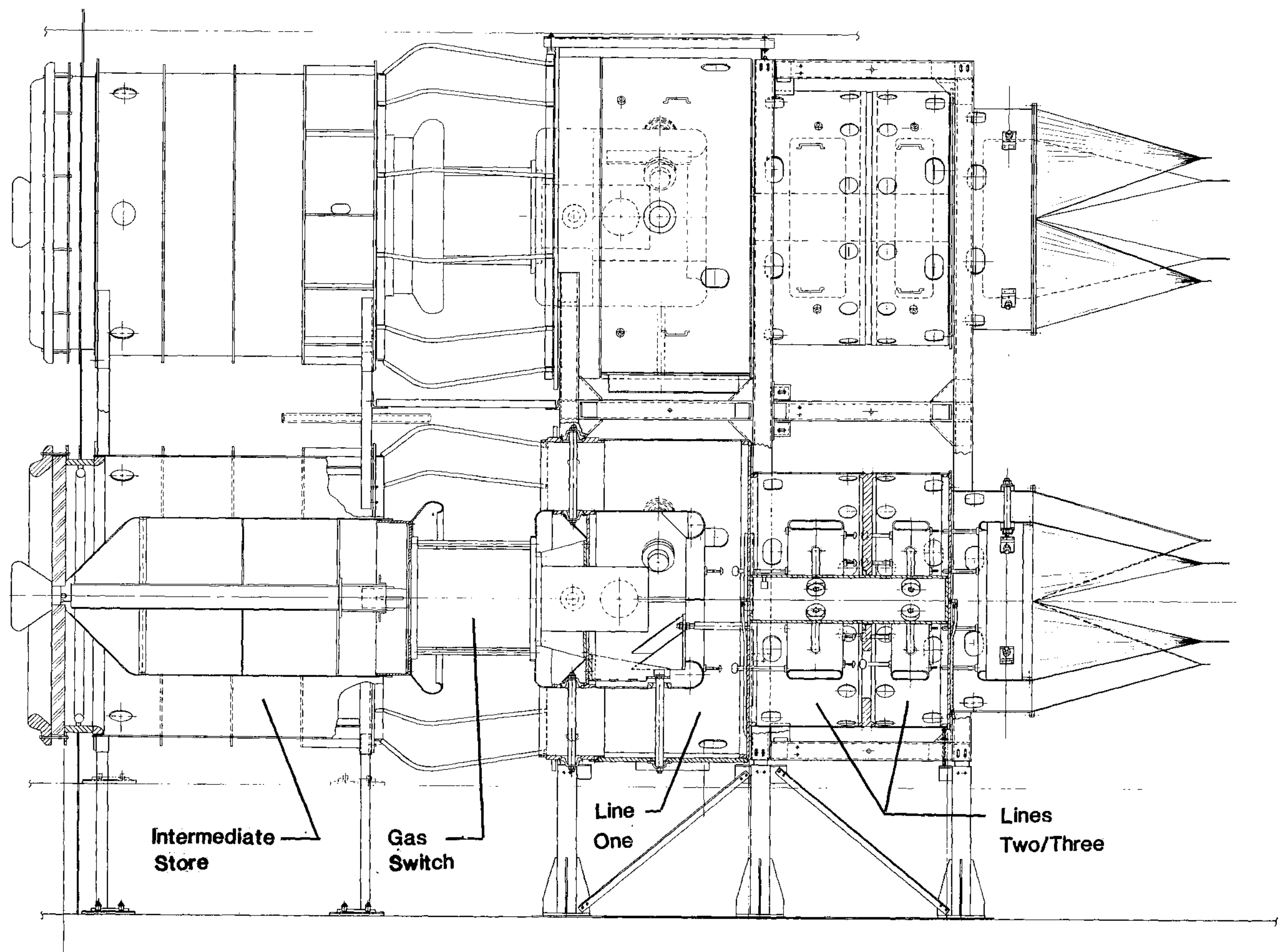

Figure 1. PFL Assembly

Two spinnings form the electrical surfaces which connect the gas switch to line one and the main portion of the inner line one itself. Line one is segmented to allow access to the laser canister. Adjustable water switch pins are mounted in bosses similar to split ring shaft clamps at the end of the line one spinning.

Horizontal support is provided by polycarbonate support rods attaching line one to prepulse shield one. These rigidly position the inner cylinder so that the laser system will remain in alignment.

The self-break water switches produce a large shock loading on the hardware. Weld cracking has been a problem in the past. This problem was addressed through careful design of the welded joints and by using a less common weld rod alloy. One weld joint which has proved to be particularly troublesome involves welding a plate to a tube with the outer surface of the plate tangent to the tube (see Fig. 3). This joint is even more difficult if the plate and tube are rolled into circular shapes before welding because the surfaces will not match exactly. Much of the weld can be ground away in an attempt to make the surfaces flush. This joint has been avoided in PBFA-II by designing spinnings and stretch wrap formed components with this shape.

The standard weld rod alloy used at Sandia for 6061-T6 aluminum is 4043. Weld rod alloys 5356 and 5556 provide both higher shear strength in fillet

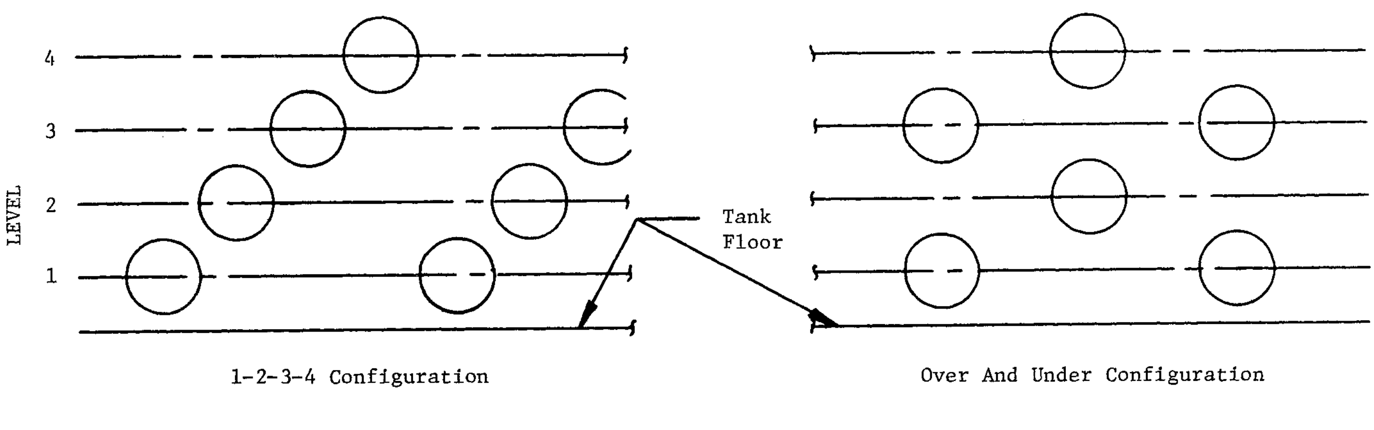

Figure 2. Possible Oil/Water Barrier Configurations.

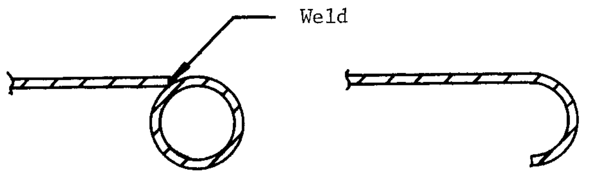

Figure 3. Welded Constriction vs. Spinning

welds and greater ductility (see Table 1). However they do not respond to heat treatment. These rods are commonly used in architectural applications in which color matching after anodizing is important. Prototype hardware built for the Demon accelerator was welded with 4043 rod. Weld cracking was seen after several hundred shots. These components were removed and examined for the quality of the welds. Most welds appears to have good penetration and fusion with the parent metal. These pieces were then rewelded using 5356 rod. The new welds have not cracked in over 300 shots on Demon.

Table 1 [1]
Properties of Fillet Welds

Filler Alloy	Shear Strength ksi	Free-bend Elongation %
1100	7.5	55
4043	11.5	15
5356	17	35
5556	20	25

Timely access to major components for maintenance was a design goal. Two areas expected to require frequent attention were the gas switch and laser system. The gas switch may be removed by sliding the intermediate store end plate back, allowing room to remove the switch without disturbing other components. Access to the laser canister requires removal of the line one outer grounds (three pieces) and line one inner cylinder. Line one outer ground planes are held in place by a spring latch. The latch consists of opposing flanges on each outer ground, a swivel bolt through the flanges and a heavy spring. Loosening the nut on the swivel bolt allows it to swing out releasing the outer ground. The spring allows some movement of the outer ground so they may "breathe" releasing the pressure built up by the arc during closing of the water switches.

Line Two/Three

Pulse forming lines two and three further compress the electrical pulse in time. The output pulse of the PFL assembly is 2.7 MV with a full width half max of 50 ns. The forward going power from each module is 2.8 TW. Lines 2 and 3 are again cylindrical transmission lines with self-break water switches. In this case, the PFL's are configured in a triaxial transmission line rather than a coaxial line as in the intermediate store and line one. The center line of the triax is charged negatively while the inner and outer cylinders remain at ground potential. The center support tube forms the center ground plane and the structural backbone of the assembly. The center conductors are 0.86 m O.D., 0.76 m I.D. toruses. These pieces are being fabricated in sections using a stretch wrap forming technique, then welded together. The outer ground planes are similar to the line one sheet metal outer panels. All outer ground planes have large holes (approx. 10 x 15 cm) spaced around the circumference. These holes serve two purposes. First they allow access into the PFL for switch pin adjustment. Second they allow the pressure pulse generated by the water switch arcs to vent preventing a pressure build up in the PFL.

The PFL's are separated by prepulse shields which prevent capacitive charging of the down line components. Prepulse shield one and three are circular flat plates with large holes for the switch pins to pass through. Prepulse shield two is a casting in the shape of a spoked wheel. A casting was chosen because of the thickness around the switch pin openings required to achieve the electrical field grading necessary to prevent premature breakdown from the switch pins to the prepulse shield.

Support Structure

In the over and under configuration, the PFLs are elevated at four different levels off the floor. They are also stacked two high. The distance between two PFLs stacked on top of each other is the same for both the high and the low lines; only the distance from the lower PFL to the floor changes. One common frame was designed with two sets of legs. The laser stand pipe which brings the laser beam up from the basement is located between two pairs of lines and feeds all four lines. The laser beam which is enclosed in an acrylic tube passes through the side of the PFL. This gives a right hand and left hand symmetry to Line One at the laser pipe feedthru. The frame and components were designed to be assembled with the frames lying horizontally on the floor. The frame is then tilted up from either side to give a right hand or a left hand unit. The ability to design one common frame for all four location requirements, high, low, left hand, and right hand, simplified the manufacturing process, reduced the number of spare parts and will reduce the complexity of installation and future maintenance.

The line one frame is separate from the line two/three frame. This modular concept was chosen to allow flexibility in assembly, allowing line one to undergo subsystem testing in PBFA-II while line 2/3 are being assembled. This arrangement also limits the amount of hardware to be removed during maintenance.

The frames are external space frames fabricated of 4 inch (10.2 cm) square aluminum tubing. The PFLs are suspended within the framework and are adjustable in two dimensions. The PFLs mount to the frames at the line one outer support ring, prepulse shield one and prepulse shield 3.

Summary

The pulse forming lines for PBFA-II have been designed under the constraints of electrical performance, maintenance and installation requirements, cost and reliability. Attention was directed to the weld design and the design for manufacturability in units of 40. The design has been partially tested in Demon with encouraging results. The design should work wellfor PFBA-II.

References

[1] Aluminum Company of America, Welding Alcoa Aluminum. Pittsburg, Pa., 1972, Tables 47 and 49.